

Table of Contents

Chapter 1

Introduction to Industrial Waste Treatment 1

1.1 Protecting People, Facilities, and the Environment 2

1.1.1 Natural Cycles 3

1.1.2 Determining Industrial Wastewater Treatment Needs 5

1.2 Water Uses 5

1.2.1 Drinking Water 5

1.2.2 Recreation 7

1.2.3 Fish, Wildlife, and Aquatic Vegetation 8

1.2.4 Agricultural Use 8

1.2.5 Industrial Use 8

1.3 Waste Discharges 11

1.3.1 Sludge and Scum 11

1.3.2 Oxygen Depletion 11

1.3.3 Human Health 12

1.3.4 Other Effects 14

1.3.5 Solids in Wastewater 14

1.3.5.1 Total Solids 14

1.3.5.2 Dissolved Solids 15

1.3.5.3 Suspended Solids 15

1.3.5.4 Organic and Inorganic Solids 15

1.3.5.5 Floatable Solids 15

1.3.6 Effects of Industrial Wastewaters 16

1.3.6.1 Effects on the Collection System 17

1.3.6.2 Effects on the Treatment System 22

1.3.6.3 Effects on Effluent and Sludge Disposal and Reuse 25

1.3.6.4 Effects on the POTW 25

1.4 Pollution Prevention 27

1.4.1 Switching from Treatment to Prevention 28

1.4.2 Pollution Control and Prevention Regulations 29

1.4.3 Economic Benefits 30

1.4.4 Pollution Prevention Opportunities 30

1.4.4.1 Best Management Practices 31

1.4.4.2 Material Substitution 33

1.4.4.3 Process Modification 33

1.4.4.4 Product Reformulation 34

1.5 Industrial Wastewater Sources 34

1.5.1 Manufacturing Processes 36

1.5.1.1 Metal Finishing Industries 37

1.5.1.2 Printed Circuit Board Manufacturing 44

1.5.2 Utility Processes 47

1.5.3 Maintenance Activities 49

1.5.4 Industrial Wastewater Treatment System 50

1.6 Industrial Wastestream Variables 51

1.6.1 Compatible and Noncompatible Pollutants 51

1.6.2 Dilute Solutions 52

1.6.3 Concentrated Solutions 52

1.6.4 Pollutant Concentration and Mass 53

1.6.5 Generation and Discharge Frequency 55

1.6.5.1 Hours of Operation and Discharge 55

1.6.5.2 Continuous and Intermittent Discharges 57

1.7 Regulatory Requirements 59

1.7.1 Environmental Protection Agency 60

1.7.1.1 Organizational Structure 60

1.7.2 Delegation of Federal Authority 61

1.7.3 Regulated Dischargers 61

1.7.4 NPDES Permit Program 62

1.7.5 National Pretreatment Program 64

1.7.5.1 General Pretreatment Regulations 64

1.7.5.2 Prohibited Discharge Standards 67

1.7.5.3 Categorical Pretreatment Standards 68

1.7.5.4 Categorical Standard Types 75

1.7.5.5 Wastestream Types 76

- 1.7.5.6 Total Toxic Organics 77
- 1.7.5.7 EPA Reporting Requirements 79
- 1.7.5.8 Categorical Standard Modifications 83
- 1.7.6 Other Federal Statutes and Regulations 85
 - 1.7.6.1 Resource Conservation and Recovery Act 85
 - 1.7.6.2 Emergency Planning and Community Right-To-Know Act of 1986 86
 - 1.7.6.3 Clean Air Act 87
 - 1.7.6.4 Hazard Communication Standard and Worker Right-to-Know Laws 87
 - 1.7.6.5 Process Safety Management of Highly Hazardous Chemicals 88
 - 1.7.6.6 Clean Water Act—Stormwater Regulations 88
 - 1.7.6.7 Hazardous Material Regulations 89
- 1.7.7 Local Wastewater Ordinances and Codes 90
 - 1.7.7.1 Additional Statements 90
 - 1.7.7.2 Administrative Fine Penalties 91
 - 1.7.7.3 EPA Minimum Requirements 92
 - 1.7.7.4 Industrial Wastewater Prohibitions 93
 - 1.7.7.5 Industrial Wastewater Limitations 93
 - 1.7.7.6 Misdemeanor and Felony Criminal Actions 95
- 1.7.8 Local Collection System Disposal Codes 95
- 1.7.9 Building Codes 96
- 1.7.10 Underground Tank Laws 96
- 1.7.11 Land Use Ordinances 97
- 1.7.12 Hazardous Waste Laws 97

1.8 Industrial Wastewater Facility Operators 98

1.9 Additional Resources 101

Chapter Review 102

**Chapter 2
Fixed Film Processes 109**

2.1 First Biological Treatment 110

2.2 Trickling Filters 110

- 2.2.1 Media 111
 - 2.2.1.1 Rock Media 115
 - 2.2.1.2 Plastic Media 116

- 2.2.2 Distribution System 117
 - 2.2.2.1 Containment Structure 120
 - 2.2.2.2 Underdrain System 121
 - 2.2.2.3 Filter Pump Station 122
 - 2.2.2.4 Secondary Clarifier 122
 - 2.2.2.5 Solids Processing Equipment 125
- 2.2.3 Safety 125
- 2.2.4 Process Monitoring and Control 126
 - 2.2.4.1 Organic Loading Rate 127
 - 2.2.4.2 Hydraulic Loading Rate 129
 - 2.2.4.3 Dosing Rate 131
 - 2.2.4.4 Recirculation Ratio 135
 - 2.2.4.5 Removal Efficiencies 136
 - 2.2.4.6 Oxygen Supply 138
 - 2.2.4.7 Sampling and Laboratory Analysis 140
 - 2.2.4.8 Daily Process Monitoring 141
- 2.2.5 Filter Classification 146
 - 2.2.5.1 Low-Rate 149
 - 2.2.5.2 Intermediate-Rate 149
 - 2.2.5.3 High-Rate 149
 - 2.2.5.4 Roughing 150
 - 2.2.5.5 Nitrifying Trickling Filters 150
- 2.2.6 Modes of Operation 151
- 2.2.7 Reviewing Plans and Specifications 153
- 2.2.8 Construction, Startup, and Shutdown 154
 - 2.2.8.1 During Construction 155
 - 2.2.8.2 Startup Procedures 156
 - 2.2.8.3 Shutdown Procedures 156
- 2.2.9 Operation and Maintenance 158
 - 2.2.9.1 Equipment Inspection and Preventive Maintenance 158
- 2.2.10 Troubleshooting 162
 - 2.2.10.1 Trickling Filter Process 163
 - 2.2.10.2 Upstream and Downstream Treatment Processes 169

2.3 Rotating Biological Contactors 170

- 2.3.1 Components 172
 - 2.3.1.1 Media 172
 - 2.3.1.2 Drive Mechanism 175
 - 2.3.1.3 Tank 177
 - 2.3.1.4 Baffles 177
 - 2.3.1.5 Covers 177
 - 2.3.1.6 Influent/Effluent Piping 177

2.3.1.7 Auxiliary Instrumentation	178
2.3.2 Process Monitoring and Control	179
2.3.2.1 Organic Loading Rate	179
2.3.2.2 Hydraulic Loading Rate	180
2.3.2.3 Oxygen Supply/Transfer	180
2.3.2.4 Rotational Speed	181
2.3.2.5 Disc Submergence	181
2.3.2.6 Biofilm Thickness	181
2.3.2.7 Recirculation Rate	182
2.3.2.8 Water and Ambient Temperature	182
2.3.3 Modes of Operation	182
2.3.4 Reviewing Plans and Specifications	186
2.3.5 Startup Procedures	186
2.3.6 Shutdown Procedures	187
2.3.7 Equipment Inspection and Preventive Maintenance	188
2.4 Submerged Fixed Film	189
2.4.1 Moving and Fixed Bed Biological Reactor Processes	191
2.4.2 Integrated Fixed Film Activated Sludge Process	192
2.4.3 Components	194
2.4.3.1 Media	194
2.4.3.2 Media Retention Sieve	197
2.4.3.3 Aeration System	197
2.4.3.4 Mixers	198
2.4.4 Process Monitoring and Control	198
2.4.4.1 Hydraulic Retention Time	199
2.4.4.2 Media Parameters	199
2.4.4.3 Substrate Parameters	200
2.4.4.4 Equivalent Suspended Solids Concentration	201
2.4.4.5 Biomass Parameters	202
2.4.4.6 Sieve Approach Velocity	202
2.4.4.7 Oxygen Parameters	203
2.4.5 Modes of Operation	204
2.4.6 Reviewing Plans and Specifications	208
2.4.7 Startup and Shutdown Procedures	209
2.4.8 Troubleshooting	210
Chapter Review	211

Chapter 3

Activated Sludge Processes 217

3.1 The Activated Sludge Process	218
3.1.1 History	219
3.1.2 Purpose	220
3.1.3 Process Description	222
3.1.3.1 Aeration	225
3.1.3.2 Secondary Clarification	230
3.1.3.3 Wasting System	232
3.1.4 Control Points	233
3.1.5 Process Variables	235
3.1.5.1 Influent Composition and Characteristics	236
3.1.5.2 Flow and Load	236
3.1.5.3 Mixed Liquor Suspended Solids	240
3.1.5.4 Sludge Volume Index	242
3.1.5.5 Food/Microorganism Ratio	245
3.1.5.6 Sludge Age	246
3.1.5.7 Return Activated Sludge	252
3.1.5.8 Waste Activated Sludge	258
3.1.6 Safety	259
3.2 Microbiology of Activated Sludge	261
3.2.1 Ecosystem Management	262
3.2.2 Microorganisms in Activated Sludge	264
3.2.2.1 Bacteria	264
3.2.2.2 Protozoa	268
3.2.2.3 Metazoa	270
3.2.2.4 Viruses, Fungi, and Algae	271
3.2.2.5 Growth Rates and Life Cycles	272
3.2.3 Microscopic Assessment and Observations	273
3.2.3.1 Sample Collection and Preparation	276
3.2.3.2 Frequency of Microscopic Observation	277
3.3 Activated Sludge Aeration	279
3.3.1 Bioreactors	280
3.3.1.1 Safety	280
3.3.2 Types of Aeration Systems	281
3.3.2.1 Diffused Air	281
3.3.2.2 Mechanical Aeration	281
3.3.2.3 High-Purity Oxygen	282

- 3.3.3 Diffused Air Systems 282
 - 3.3.3.1 Blowers 284
 - 3.3.3.2 Diffusers 292
 - 3.3.3.3 Air Distribution System 297
 - 3.3.3.4 Air Headers 298
- 3.3.4 Surface Aerators 300
 - 3.3.4.1 Fixed Mounted Aerators 300
 - 3.3.4.2 Floating 303
 - 3.3.4.3 Turbine 303
 - 3.3.4.4 Operation 304
 - 3.3.4.5 Maintenance 304
 - 3.3.4.6 Safety 305
- 3.3.5 Mixers 306
 - 3.3.5.1 Submersible 307
 - 3.3.5.2 Surface-Mounted 307
- 3.3.6 Recirculation Pumps 307
 - 3.3.6.1 Operation 308
 - 3.3.6.2 Maintenance 308
 - 3.3.6.3 Safety in Pump Rooms 310
- 3.3.7 Flow Pattern 311
 - 3.3.7.1 Flow Control Equipment 311
 - 3.3.7.2 Plug Flow 312
 - 3.3.7.3 Complete Mix 312
 - 3.3.7.4 Step-Feed 313
 - 3.3.7.5 Contact Stabilization 316

3.4 Secondary Clarification 317

- 3.4.1 Design Guidelines 318
- 3.4.2 Configurations 321
 - 3.4.2.1 Round 321
 - 3.4.2.2 Rectangular 323
- 3.4.3 Operation and Maintenance 324
- 3.4.4 State Point Analysis 326
 - 3.4.4.1 Practical Applications 329

3.5 Process Configuration 336

- 3.5.1 Common AS Process Modifications 336
 - 3.5.1.1 Nutrient Removal 336
 - 3.5.1.2 Kraus Process 340
 - 3.5.1.3 High-Purity Oxygen Systems 341
 - 3.5.1.4 Oxidation Ditches 343
- 3.5.2 Process Variations 344
 - 3.5.2.1 Membrane Bioreactors 344
 - 3.5.2.2 Sequencing Batch Reactors 345

3.6 Process Control 349

- 3.6.1 Operational Strategy 350
 - 3.6.1.1 Target Secondary Effluent Quality 350
 - 3.6.1.2 Plan for Variation 351
 - 3.6.1.3 Process Monitoring and Data Collection Plan 352
 - 3.6.1.4 Maintenance and Equipment Tracking 352
 - 3.6.1.5 Chemical and Supply Inventory 353
 - 3.6.1.6 Recordkeeping 353
- 3.6.2 Process Automation 354
 - 3.6.2.1 Automation System Architecture 354
 - 3.6.2.2 Automation Control Strategies and Applications 357
 - 3.6.2.3 Frequently Automated Processes 358
- 3.6.3 Monitoring and Data Collection 360
 - 3.6.3.1 Monitoring Tools 360
 - 3.6.3.2 Measurements and Testing 362
 - 3.6.3.3 Process Performance Monitoring 363
 - 3.6.3.4 Process Inspection 364
 - 3.6.3.5 Laboratory Testing 365
 - 3.6.3.6 Data Analysis and Review 366
 - 3.6.3.7 Recordkeeping 368
- 3.6.4 Process Adjustments 370
 - 3.6.4.1 Wasting Rate 371
 - 3.6.4.2 RAS Flow 372
 - 3.6.4.3 Aeration Rate 373
 - 3.6.4.4 Responding to Results 373

3.7 Abnormal Operation and Troubleshooting 374

- 3.7.1 Major Causes 375
 - 3.7.1.1 Hydraulic Variations 375
 - 3.7.1.2 Water Quality Changes 376
 - 3.7.1.3 Equipment Malfunction 377
 - 3.7.1.4 Facility Changes 377
 - 3.7.1.5 Inadequate or Failed Process Control 378
 - 3.7.1.6 Environmental Changes 378
 - 3.7.1.7 Design Deficiency 378
- 3.7.2 Common Problems and Solutions 379
 - 3.7.2.1 Aeration System Problems 380
 - 3.7.2.2 Toxicity 383
 - 3.7.2.3 Foaming 383
 - 3.7.2.4 Bulking 387
 - 3.7.2.5 Clumping or Rising Sludge 391
 - 3.7.2.6 Ashing 392

- 3.7.2.7 Pinpoint Floc 393
- 3.7.2.8 Straggler Floc 393
- 3.7.2.9 Cloudy Effluent 393
- 3.7.2.10 Septic Sludge 395
- 3.7.3 Troubleshooting 396
 - 3.7.3.1 Equipment Operation Under Abnormal Conditions 397

3.8 System Startup and Shutdown 412

- 3.8.1 Reviewing Plans and Specifications 413
 - 3.8.1.1 Drawings 414
 - 3.8.1.2 Specifications 418
- 3.8.2 Inspection 421
 - 3.8.2.1 Flow Control Gates, Valves, and Weirs 422
 - 3.8.2.2 Water Sprayers 423
 - 3.8.2.3 Air Filters 423
 - 3.8.2.4 Air Headers 424
 - 3.8.2.5 Diffusers 425
 - 3.8.2.6 Blowers and Compressors 425
 - 3.8.2.7 Secondary Clarifiers 427
 - 3.8.2.8 RAS and WAS Pumps 427
- 3.8.3 Startup Procedures 428
 - 3.8.3.1 Day 1 429
 - 3.8.3.2 Day 2 430
 - 3.8.3.3 Days 3 Through 5 431
 - 3.8.3.4 Day 6 431
- 3.8.4 Instrumentation and Control 431
- 3.8.5 Short-Term Shutdown 433
- 3.8.6 Long-Term Shutdown and Restarting 434
 - 3.8.6.1 Shutdown Procedures 434
 - 3.8.6.2 Restarting the System 435

3.9 Industrial Wastewater Treatment Using Activated Sludge 437

- 3.9.1 Dairies 437
 - 3.9.1.1 Characterization of Dairy Wastewater 437
 - 3.9.1.2 Configurations 438
- 3.9.2 Breweries 439
 - 3.9.2.1 Characterization of Brewery Wastewater 440
 - 3.9.2.2 Components and Operation 440
 - 3.9.2.3 Filamentous Organisms 441
- 3.9.3 Pulp and Paper 441
 - 3.9.3.1 Wastewater Characteristics 442
 - 3.9.3.2 Nutrient Control 442

- 3.9.3.3 Foam Control 442
- 3.9.3.4 pH Control 443
- 3.9.3.5 Fiber 443
- 3.9.3.6 Flow 444
- 3.9.3.7 Settleability 444
- 3.9.3.8 Color and Turbidity 444
- 3.9.3.9 Odor 445

- 3.9.4 Petroleum Refineries 445
 - 3.9.4.1 Operation 445
 - 3.9.4.2 Treating Toxic Substances 445

Chapter Review 447

Chapter 4 Nutrient Removal 453

4.1 Biological Treatment Processes 454

- 4.1.1 Rate Limiting Nutrient 455

4.2 Nitrogen Removal 458

- 4.2.1 Nitrification 459
 - 4.2.1.1 Process Efficiency 461
 - 4.2.1.2 Suspended Growth Reactors 464
 - 4.2.1.3 Fixed Film Reactors 473
 - 4.2.1.4 Laboratory Reporting and Regulatory Compliance 479
 - 4.2.1.5 Troubleshooting 480
- 4.2.2 Denitrification 482
 - 4.2.2.1 Fixed Film Reactors 483
 - 4.2.2.2 Suspended Growth Reactors 484
 - 4.2.2.3 Troubleshooting 486
- 4.2.3 Ammonia Stripping 486
 - 4.2.3.1 Troubleshooting 489
- 4.2.4 Breakpoint Chlorination 490
 - 4.2.4.1 Equipment 491
 - 4.2.4.2 Operation 492
- 4.2.5 Ion Exchange 492
- 4.2.6 Anammox Treatment Process 493
- 4.2.7 Overland Flow 495

4.3 Phosphorus Removal 495

- 4.3.1 Biological Phosphorus Removal 497
 - 4.3.1.1 Process Configurations 499

- 4.3.2 Enhanced Biological Phosphorus Removal 500
 - 4.3.2.1 Safety 502
 - 4.3.2.2 Equipment 503
 - 4.3.2.3 Startup 504
 - 4.3.2.4 Operation 504
 - 4.3.2.5 Shutdown 507
 - 4.3.2.6 Abnormal and Emergency Operating Conditions 508
 - 4.3.2.7 Maintenance 508
 - 4.3.2.8 Calculating Process Efficiency 509
 - 4.3.2.9 Reviewing Plans and Specifications 509
- 4.3.3 Chemical Phosphorus Removal 511
 - 4.3.3.1 Aluminum Sulfate 513
 - 4.3.3.2 Ferric Chloride 515
 - 4.3.3.3 Chemical Injection Locations 516
 - 4.3.3.4 Sludge Production 518
 - 4.3.3.5 Maintenance 519
 - 4.3.3.6 Reviewing Plans and Specifications 520
- 4.3.4 Lime Precipitation 521
 - 4.3.4.1 Equipment 521
 - 4.3.4.2 Operation 523
 - 4.3.4.3 Sampling and Analysis 523
 - 4.3.4.4 Recarbonation and Calcium Carbonate Recapture 524
 - 4.3.4.5 Abnormal and Emergency Conditions 526
 - 4.3.4.6 Maintenance 527
 - 4.3.4.7 Loading Guidelines 529
 - 4.3.4.8 Reviewing Plans and Specifications 530

4.4 Enhanced Biological Control 531

- 4.4.1 Multiple Processing Objectives 531
 - 4.4.1.1 Process Control 533
 - 4.4.1.2 System Flexibility 533
 - 4.4.1.3 Operating Strategy 534
- 4.4.2 Bardenpho Process 534
 - 4.4.2.1 Operation 537
- 4.4.3 Sequencing Batch Reactors 537
- 4.4.4 Optimizing Nitrogen and Phosphorus Removal 538
- 4.4.5 Enhanced SVI Control 541
 - 4.4.5.1 Operation and Troubleshooting 542
- 4.4.6 Reviewing Plans and Specifications 544
 - 4.4.6.1 Overall Facility 544
 - 4.4.6.2 Enhanced Phosphorus Control 549

- 4.4.6.3 Enhanced Nitrogen Oxidation 549
- 4.4.6.4 Enhanced Nitrogen Removal 550
- 4.4.6.5 Enhanced SVI Control 551

Chapter Review 553

**Chapter 5
Anaerobic Treatment 557**

5.1 Introduction to Industrial Anaerobic Treatment 558

- 5.1.1 Anaerobic Process 560
 - 5.1.1.1 Microorganisms in Anaerobic Treatment Processes 562
- 5.1.2 Anaerobic Applications 563
- 5.1.3 Safety 567
- 5.1.4 Anaerobic Reactors 568
 - 5.1.4.1 Suspended Growth Anaerobic Reactors 568
 - 5.1.4.2 Attached Growth Anaerobic Reactors 573
 - 5.1.4.3 Hybrid Anaerobic Reactors 574
- 5.1.5 Anaerobic Process Parameters 575
 - 5.1.5.1 Wastewater Flow and Organic Loading 575
 - 5.1.5.2 Organic Removal Efficiency 577
 - 5.1.5.3 Wastewater Alkalinity 577
 - 5.1.5.4 pH Adjustment 578
 - 5.1.5.5 Nutrient Requirements 579
 - 5.1.5.6 Toxic and Inhibitory Substances 581
 - 5.1.5.7 Sulfur Compounds and Sulfide Production 583
 - 5.1.5.8 Volatile Fatty Acids 583
 - 5.1.5.9 Volatile Acid to Alkalinity Ratio 584
 - 5.1.5.10 Solids Retention Time 585
 - 5.1.5.11 Hydraulic Retention Time 585
 - 5.1.5.12 Temperature 586
 - 5.1.5.13 Solids Wasting 587
 - 5.1.5.14 Effluent Recycle 588
 - 5.1.5.15 Gas Production, Composition, and Energy Value 589

5.2 Configurations 590

- 5.2.1 Pretreatment Units 591
 - 5.2.1.1 Equalizing and Conditioning Basin 591

5.2.1.2	Chemical Feed System and Location	592
5.2.1.3	Temperature Control	592
5.2.2	Upflow Anaerobic Sludge Blanket Process	594
5.2.2.1	Granular Sludge	595
5.2.2.2	Advantages of the UASB Process	597
5.2.2.3	Process Components	598
5.2.2.4	Process Parameters	600
5.2.3	Anaerobic Contact Process and Anaerobic Membrane Bioreactors	601
5.2.4	Attached Growth Process	602
5.2.4.1	Fixed Film Attached Growth Process	603
5.2.4.2	Tank Configuration	604
5.2.4.3	Fixed Film Media Materials	605
5.2.4.4	Process Parameters	607
5.2.5	Hybrid Process	607
5.2.6	Post-Treatment Units	608
5.2.6.1	Biomass Handling System	608
5.2.6.2	Biogas Handling System	609
5.3 Operation and Maintenance 611		
5.3.1	Operational and Performance Guidelines	612
5.3.1.1	Maintaining Steady Wastewater Flow and Loading	612
5.3.1.2	Maintaining Anaerobic Conditions	612
5.3.1.3	Contact Between Substrate and Microorganisms	612
5.3.1.4	Maintaining the Reactor Environment	613
5.3.2	Startup Procedure	614
5.3.2.1	Before Startup	614
5.3.2.2	Startup	615
5.3.3	Operation	617
5.3.3.1	Normal Operating Guidelines	617
5.3.3.2	Process Monitoring and Control Guidelines	620
5.3.3.3	Gas Collection and Handling	624
5.3.3.4	Odor Control	625
5.3.3.5	Laboratory Procedures	626
5.3.4	Abnormal Operation and Troubleshooting	633
5.3.4.1	Upset Condition Indicators	633
5.3.4.2	Causes of Upsets and Solutions	633
5.3.4.3	Troubleshooting Guidelines	637
5.3.5	Shutdown Procedures	645
5.3.6	Restarting After Shutdown	646

5.3.7	Maintenance	647
5.3.7.1	Daily Maintenance	647
5.3.7.2	Preventive Maintenance	648

Chapter Review 651

Chapter 6

Residual Solids Management 655

6.1 Solids Handling and Disposal 656

6.1.1	Solids Types and Characteristics	657
6.1.2	Preparing Solids for Disposal and Reuse	660
6.1.3	Sludge Treatment, Reuse, and Disposal Regulations	660
6.1.3.1	Solid Waste	661
6.1.3.2	Hazardous Waste	662
6.1.3.3	Land Disposal Restrictions	664
6.1.3.4	Solids Discharged to POTWs	665
6.1.4	Sludge Quantities	665
6.1.4.1	Primary Sludge	666
6.1.4.2	Secondary Sludge	667
6.1.4.3	Sludge Volumes	669
6.1.5	Sludge Handling Methods	670

6.2 Preliminary Sludge Processing 671

6.3 Sludge Thickening 673

6.3.1	Gravity Thickeners	675
6.3.1.1	Performance	675
6.3.1.2	Operation	681
6.3.1.3	Troubleshooting	683
6.3.2	Dissolved Air Flotation Thickeners	692
6.3.2.1	Performance	695
6.3.2.2	Operation	700
6.3.2.3	Troubleshooting	702
6.3.3	Centrifuge Thickeners	704
6.3.3.1	Solid Bowl Centrifuge	705
6.3.3.2	Basket Centrifuge	706
6.3.3.3	Disc-Nozzle Centrifuge	707
6.3.3.4	Performance	707
6.3.3.5	Operation	713
6.3.3.6	Troubleshooting	715
6.3.4	Gravity Belt Thickeners	719
6.3.4.1	Performance	721

- 6.3.4.2 Operation 723
- 6.3.4.3 Troubleshooting 724
- 6.3.5 Rotary Drum Thickeners 725
 - 6.3.5.1 Performance 727
 - 6.3.5.2 Operation 728
- 6.4 Sludge Stabilization 729**
 - 6.4.1 Anaerobic Digestion 730
 - 6.4.1.1 Process Description 730
 - 6.4.1.2 System Components 735
 - 6.4.1.3 Digester Mixing 745
 - 6.4.1.4 Digester Heating 749
 - 6.4.1.5 Digester Gas Collection 753
 - 6.4.1.6 Digester Gas Treatment 761
 - 6.4.1.7 Performance 766
 - 6.4.1.8 Digester Operation 772
 - 6.4.1.9 Controls and Test Interpretation 782
 - 6.4.1.10 Digester Cleaning 794
 - 6.4.1.11 Safety 797
 - 6.4.1.12 Operational Strategy 797
 - 6.4.1.13 Troubleshooting 804
 - 6.4.1.14 Example of Actual Operation 805
 - 6.4.2 Aerobic Digestion 807
 - 6.4.2.1 Process Description 808
 - 6.4.2.2 Performance 811
 - 6.4.2.3 Operation 817
 - 6.4.2.4 Typical Performance 821
 - 6.4.2.5 Troubleshooting 823
 - 6.4.3 Chemical Stabilization 827
 - 6.4.3.1 Operation 829
 - 6.4.3.2 Troubleshooting 829
 - 6.4.4 Composting 829
 - 6.4.4.1 Performance 833
 - 6.4.4.2 Operation 836

- 6.4.4.3 Troubleshooting 837
- 6.4.4 Facultative Sludge Storage Lagoons 838

6.5 Dewatering and Volume Reduction 839

- 6.5.1 Filtration 840
 - 6.5.1.1 Filter Press 840
 - 6.5.1.2 Belt Filter Press 848
 - 6.5.1.3 Screw Press 854
 - 6.5.1.4 Rotary Press 857
- 6.5.2 Centrifugation 860
 - 6.5.2.1 Performance 860
- 6.5.3 Sludge Drying 860
 - 6.5.3.1 Sand Drying Beds 861
 - 6.5.3.2 Surfaced Drying Beds 867
 - 6.5.3.3 Heat Drying 870
- 6.5.4 Sludge Incineration 874
 - 6.5.4.1 Multiple Hearth Incinerator 874
 - 6.5.4.2 Fluidized Bed Incinerator 878
 - 6.5.4.3 Performance 878
 - 6.5.4.4 Operation 880
 - 6.5.4.5 Troubleshooting 883

6.6 Solids Disposal 884

Chapter Review 886

Answer Key 891

Glossary 895

Index 923

Index

Note: Page number followed by *f* and *t* refers to figures and tables respectively.

- A**
- A²O process, 339
- Abnormal operating conditions, anaerobic reactor
 - nutrient deficiencies, 635–636
 - overfeeding, 633–634
 - pH extremes, 634–635
 - temperature extremes, 635
 - toxic substances, 636
 - upset condition indicators, 633
- Acetogenesis, 561
- Acid formers, 562
- Acidogenesis, 560–561
- Activated carbon, 762
- Activated sludge, 110, 221, 465–466
- Activated sludge aeration
 - bioreactors, 280–281
 - diffused air systems, 282–300
 - flow pattern, 311–317
 - mixers, 306–307
 - recirculation pumps, 307–310
 - surface aerators, 300–306
 - types of aeration systems, 281–282
- Activated sludge process
 - abnormal operation and troubleshooting, 374–375
 - common problems and solutions, 379–396
 - design deficiency, 378–379
 - environmental changes, 378
 - equipment malfunction, 377
 - facility changes, 377–378
 - hydraulic variations, 375–376
 - inadequate or failed process control, 378
 - troubleshooting, 396–397, 398*f*–411*f*; 401, 406, 408, 412
 - water quality changes, 376–377
- activated sludge aeration, 279
 - bioreactors, 280–281
 - diffused air systems, 282–300
 - flow pattern, 311–317
 - mixers, 306–307
 - recirculation pumps, 307–310
 - surface aerators, 300–306
 - types of aeration systems, 281–282
- defined, 220, 458, 657
- history, 219–220
- industrial wastewater treatment
 - breweries, 439–441
 - dairies, 437–439
 - petroleum refineries, 445–446
 - pulp and paper, 441–445
- microbiology of activated sludge, 261–262
 - ecosystem management, 262–263
 - microorganisms in activated sludge, 264–272
 - microscopic assessment and observations, 273–279
- process configuration
 - common AS process modifications, 336–343
 - process variations, 344–348
- process control, 349–350
 - monitoring and data collection, 360–370
 - operational strategy, 350–353
 - process adjustments, 370–374
 - process automation, 354–359
- process description, 222–225
 - aeration, 225–229
 - control points, 233–235
 - process variables, 235–259
 - safety, 259–261
 - secondary clarification, 230–232
 - wasting system, 232–233
- purpose, 220–222
- secondary clarification, 317
 - configurations, 321–324
 - design guidelines, 318–321
 - operation and maintenance, 324–326
 - state point analysis, 326–335
- system startup and shutdown, 412–413
 - inspection, 421–428
 - instrumentation and control, 431–432
 - long-term shutdown and restarting, 434–436
 - reviewing plans and specifications, 413–421
 - short-term shutdown, 433–434
 - startup procedures, 428–431
- Acute health effect, 6
- Adsorption, 511, 596, 762
- Aeration
 - bioreactors and aeration tanks, 225–226
 - defined, 221, 483
 - dissolved oxygen, 226–227
 - environmental conditions, 229
 - maintaining the microbial population, 227–229
- Aeration basin, 464. *See also* Suspended growth reactors
- Aeration tank, 218, 220
- Aerobic, 225
- Aerobic bacteria, 11, 110, 225
- Aerobic biological treatment processes, 138
- Aerobic digestion
 - vs.* anaerobic, 809*t*
 - defined, 670
 - operation
 - process control and monitoring, 817–820
 - startup and shutdown, 820–821
 - performance
 - air requirements and dissolved oxygen, 815–816
 - alkalinity and pH, 816
 - digestion temperature, 813–814
 - digestion time, 813
 - sludge quality, 811–813
 - volatile solids loading, 814–815
 - process description
 - autothermal thermophilic aerobic digestion process, 810–811
 - conventional aerobic digester, 810
 - high-purity oxygen aerobic digester, 810
 - process schematic, 807, 808*f*
 - troubleshooting
 - foaming, 827
 - guide, 823, 824*f*–825*f*
 - loadings, 827
 - residual DO upset, 825
 - temperature and pH, 825–826
 - typical performance, 821–823
- Aerobic environment, 464
- Aerobic process, 138
- Aerobic wastewater treatment, 454, 558
- Agglomeration, 223
- Air distribution system
 - maintenance, 297–298
 - operational procedures, 297
 - safety, 298
- Air filters, 423–424
- Air headers
 - maintenance, 298–299
 - safety, 299–300
 - system startup and shutdown, 424–425

- Algae, 3, 111, 264, 271, 454
- Alkalinity
 defined, 224, 459, 745
 and pH, 468–472
 wastewater, 577–578
- Alum. *See* Aluminum sulfate
- Aluminum sulfate, 513–515
- Ammonia-oxidizing bacteria (AOB),
 459–461, 466, 469, 470
- Ammonia stripping process, 486–490
- Amoebas, 269, 269*f*
- Anaerobic bacteria, 12, 225, 264, 560
- Anaerobic conditions, 127
- Anaerobic contact process (ANCP), 564,
 564*t*, 565, 570, 601–602
- Anaerobic decomposition, 396
- Anaerobic denitrification zone, 534
- Anaerobic digester, 503
- Anaerobic digestion
 controls and test interpretation
 digester gas production, 788
 other calculations, 792–794
 pH, 783
 sludge volume, 783–784
 solids mass balance, 788–792
 solids test, 783
 temperature, 782
 volatile acid/alkalinity, 782–783
 volatile solids reduction, 784–788
 defined, 125, 238, 560, 670
 digester cleaning
 cleaning methods and necessary
 equipment, 796
 example, 794–795
 factors, 795
 digester gas collection
 components and accessories, 754,
 754*f*
 gas dome, 754
 meters, 760
 moisture traps, 758–760
 pressure- and vacuum-relief valves,
 754, 756
 pressure regulator, 760–761
 thermal protection devices, 756–758
 troubleshooting guidelines, 754, 755*f*
 waste gas burner, 761
 digester gas treatment
 digester gas storage, 764–765
 digester gas use, 765–766
 hydrogen sulfide removal, 762, 763*f*
 moisture removal, 763–764
 siloxane removal, 764
 digester heating, 749, 751*f*–753*f*
 digester mixing
 gas mixing, 745, 746*f*
 mechanical mixing, 745–749, 750*f*
 digester operation
 decanting, 779, 779*f*–781*f*
 digester feeding, 773–774
 enzymes, 777
 foaming, 777–778
 gas production, 778
 neutralizing a sour digester, 774–777
 sludge withdrawal, 778
 struvite control, 779, 781*t*
 supernatant and solids, 778
 example of actual operation, 805–807
 operational strategy
 activities, 798–799
 shutting down a digester, 803–804
 starting a digester, 799–803
 typical performance, 804
 performance
 inhibitory substances, 771, 772*t*
 mixing, 769
 pH and alkalinity, 770
 solids and hydraulic retention times,
 767–769
 temperature, 770
 process description
 feed sludge pretreatment, 733–734
 mixing, 732
 multistage digestion, 733
 primary and secondary digestion, 733
 stages, 731, 731*f*
 temperature, 732
 thermophilic digestion, 732
 two-phase digestion, 733
 safety, 797
 system components
 digester covers, 739–744
 digester tank, 736–739
 pipelines and valves, 735–737
 troubleshooting, 804, 805*t*
 Anaerobic digestion process stages, 731,
 731*f*
 Anaerobic environment, 464
 Anaerobic filters (ANF), 565, 573–574
 Anaerobic fluidized bed (ANFB) reactor,
 574
 Anaerobic granular sludge, 595
 Anaerobic lagoons, 571–572
 Anaerobic membrane bioreactors
 (AnMBR), 570–571, 602
 Anaerobic process parameters
 effluent recycle, 588–589
 gas production, composition, and energy
 value, 589–590
 hydraulic retention time, 585–586
 nutrient requirements, 579–581
 organic removal efficiency, 577
 pH adjustment, 578–579
 solids retention time, 585
 solids wasting, 587–588
 sulfur compounds and sulfide
 production, 583
 temperature, 586
 toxic and inhibitory substances, 581–583
 volatile acid to alkalinity ratio, 584
 volatile fatty acids, 583–584
 wastewater alkalinity, 577–578
 wastewater flow and organic loading,
 575–577
- Anaerobic selector, 205, 499
- Anaerobic sequencing batch reactor, 572
- Anaerobic system components, 559–560
- Anaerobic treatment
 abnormal operating conditions
 nutrient deficiencies, 635–636
 overfeeding, 633–634
 pH extremes, 634–635
 temperature extremes, 635
 toxic substances, 636
 upset condition indicators, 633
 anaerobic reactors (*see* Attached growth
 anaerobic reactors; Hybrid
 anaerobic reactors; Suspended
 growth anaerobic reactors)
 applications, 563–566
 configurations, 590
 anaerobic contact process, 601–602
 anaerobic membrane bioreactors, 602
 attached growth process, 602–607
 hybrid process, 607–608
 post-treatment units, 608–610
 pretreatment units, 591–594
 upflow anaerobic sludge blanket
 process, 594–601
 daily maintenance, 647–648
 defined, 558
 dry shutdown procedures, 646
 efficiency, 563
 gas collection and handling, 624–625
 laboratory procedures
 biogas analysis, 630–632
 BOD/COD determination, 632
 BOD/COD reduction, 632
 total alkalinity and volatile acids,
 626–630
 total Kjeldahl nitrogen method, 633
 total suspended solids, 632
 microorganisms in, 562
 normal operating guidelines, 617–620
 odor control, 625–626
 operational and performance guidelines,
 612–614
 operational limitations, 563–564
 practices for successful operation, 611
 preventive maintenance, 648–650
 process monitoring and control
 guidelines, 620
 biogas, 623–624
 influent flow, 621
 organic reduction, 621–622
 sludge management, 622–623
 restart procedures, 646–647
 safety, 567
 startup procedure, 614–617
 troubleshooting, 637–644
 wet shutdown procedures, 645–646
 Anaerobic *vs.* aerobic process, 558, 559*f*
 Analog, 354
 Anammox treatment process, 493–495
 Anhydrous ammonia, 580, 774
 Anhydrous form, 515

Anionic polymers, 695
 Annular space, 742
 Anodizing, 37, 40–41
 Anoxic, 170, 225, 809
 Anoxic denitrification, 191, 532
 Anoxic environment, 464
 Anoxic zones, 534, 546, 547
 Appurtenances, 282
 Arching, 510
 Ashing, 365, 392–393
 Aspiration, 302
 Aspirator, 693
 Atomic Energy Act, 663
 Attached growth anaerobic process
 fixed film attached growth process, 603, 604
 fixed film media materials, 605–607
 process parameters, 607
 tank configuration, 604–605
 Attached growth anaerobic reactors, 573–574
 Attached growth processes, 461
 Autotrophic bacteria, 147, 459
 Autotrophs, 266

B

Back-spray orifices, 118
 Bacteria, 111, 218, 219, 264–268, 454, 562
 Bacterial granulation process, 596
 Baffles, 172, 233, 480
 Bardenpho process, 339–340, 534–537
 Baseline monitoring reports (BMR), 66, 80–81
 Basket centrifuge, 706–707, 707*f*
 Batch process, 706
 Belt filter press, 848–854
 Best demonstrated available technology (BDAT), 664, 665*t*
 Best management practices (BMPs)
 audits and management support, 32–33
 material distribution systems, 31–32
 process operations, 32
 raw material and product storage and loading, 31
 raw material purchasing, 31
 waste segregation, 32
 Biochemical oxygen demand (BOD), 35, 110, 220, 221, 454, 575, 577, 657, 658
 Biodegradable, 218, 220
 Biofilters, 110
 Biogas handling system, 609–610
 Biogas scrubbing tower for hydrogen sulfide, 762, 763*f*
 Biological process, 219, 454, 658, 659
 Biological wastewater treatment, 218, 454–458
 Biomass, 111, 114, 219, 220, 460, 560
 Biomass handling system, 608

Bioreactors, 280–281
 Biosolids, 29
 Biotowers, 110
 Blinding, 720
 Blowdown, 16
 Blower air filters, 287
 Blowers
 blower air filters, 287
 centrifugal blower, 286–287
 defined, 281, 425–427
 diffused air aeration system, 284–285
 maintenance, 288–291
 operational procedures, 287–288
 positive displacement, 285
 rotary screw blower, 286
 safety, 291–292
 turbo blowers, 287
 BOD. *See* Biochemical oxygen demand (BOD)
 Breakpoint chlorination process
 defined, 458
 equipment, 491–492
 nitrogen removal, 490–491
 operation considerations, 492
 Breweries
 characterization of brewery wastewater, 440
 components and operation, 440–441
 filamentous organisms, 441
 Bright dipping process, 41
 British thermal units (BTU), 753
 Brown foam, 385–387, 386*f*
 Buffer capacity, 469, 578, 770
 Buffering, 468
 Buffer solutions, 627
 Building codes, 96
 Bulking, 258, 387–391, 480

C

Carbonaceous matter, 579
 Categorical standard modifications
 fundamentally different factors, 83–84
 net gross calculations, 84
 removal credits, 84–85
 Categorical standards, 37
 Cationic polymers, 389, 695
 Cavitation, 693
 Centrate, 507, 705
 Centrifugal blower, 286–287
 Centrifugal pumps, 307, 699
 Centrifuge, 675
 Centrifuge designs for dewatering sludge, 860
 Centrifuge thickeners
 advantages, 705
 basket centrifuge, 706–707
 disadvantages, 705
 disc-nozzle centrifuge, 707
 operation, 713–715
 performance
 bowl speed, 710, 712
 and differential speed, 712
 feed time, 710–712
 hydraulic and solids loadings, 709–710
 liquid depth, 712
 nozzle size and number, 712
 polymer dose, 712–713
 solid bowl centrifuge, 705–706
 troubleshooting
 basket centrifuge, 718–719
 disc-nozzle centrifuge, 719
 solid bowl centrifuge, 716–718
 Chain of custody, 94
 Chelating agent, 39
 Chelation, 20
 Chemical feed system and location, 592
 Chemical injection location for phosphorus removal, 517–518
 Chemical milling, 41
 Chemical oxygen demand (COD), 28, 144, 237, 471, 558
 Chemical phosphorus removal process
 aluminum sulfate, 513–515
 chemical injection locations, 516–518
 ferric chloride, 515–516
 maintenance, 519–520
 reviewing plans and specifications, 520
 sludge production, 518–519
 Chemical stabilization, 827–829
 Chloramines, 490
 Chlorine demand, 144
 Chlorine residual, 490
 Chronic health effect, 6
 Ciliates, 268, 270, 270*f*, 271*f*
 Clarification, 234
 Clarifiers, 479
 Clarity, 145
 Clean Air Act Amendments of 1990, 87
 Cleaning and surface preparation, 37–39
 Clean Water Act, 88–89
 Cloudy effluent, 393–395, 394*t*, 395*t*
 Clumping/rising sludge, 391–392
 C:N:P ratios, 454
 Coagulation, 521
 Coarse bubble diffusers, 292–293
 COD. *See* Chemical oxygen demand (COD)
 COD/BOD ratio, 576, 577
 Codigestion, 566
 Coliform bacteria, 64, 145
 Coliform counts, 145–146
 Colloid, 218, 219
 Colloidal, 695
 Colloidal lime, 503
 Combined heat and power unit, 765, 766*f*
 Compatible pollutants, 23
 Complete mix activated sludge process, 312–313, 313*f*, 465
 Compliance schedule, 81
 Composite samples, 137, 276, 700–702

- Composting
 guidelines, 829–830
 operation, 836–837
 performance, 833–836
 static pile, 830
 troubleshooting, 837, 838*f*
 windrow method, 830, 832*f*
- Compressors, 425–427
- Computer maintenance management
 systems (CMMSs), 353
- Condensate and sediment trap, 759, 759*f*
- Conditioning basin, 592
- Conductivity, 23
- Confined spaces, 259, 567, 742
- Coning, 685
- Contact stabilization, 270, 316–317, 316*f*,
 317*t*, 465
- Continuous feed system, 705
- Continuously stirred tank anaerobic
 reactor, 569–570
- Conventional pollutants, 28
- Corrosion, 742
- Corrosion-resistant coating, 592
- Cradle-to-grave, 659
- Cross-flow filtration, 344
- Cross-flow media, 117
- Cylindrical digester, 737, 738*f*
- D**
- Daily maintenance of anaerobic treatment
 system, 647–648
- Daily process monitoring
 chemical oxygen demand, 144
 chlorine demand, 144
 clarity, 145
 coliform counts, 145–146
 dissolved oxygen, 144
 5-day biochemical oxygen demand,
 143–144
 nutrients, 145
 pH, 145
 total suspended solids (TSS), 143
- Dairies
 characterization of dairy wastewater,
 437–438
 configurations, 438–439
- Dangerous air conditions, 742
- Dead-end filtration, 344
- Decibel, 285
- Delegation of federal authority, 61
- Denitrification
 chemical reaction with organic matter,
 483
 defined, 124, 222, 458
 fixed film reactors, 483–484
 suspended growth reactors, 484–486
 troubleshooting guide, 486, 487
- Densities, 658
- Detention time, 127, 464, 667
- Dewatering, 125, 504, 656, 657, 657*f*
 gas production, 778
 neutralizing a sour digester, 774–777
 sludge withdrawal, 778
 struvite control, 779, 781*t*
 supernatant and solids, 778
- Digester tank, 736–739
- Digestion. *See* Aerobic digestion *and*
 Anaerobic digestion
- Direct dischargers, 350
- Disc-nozzle centrifuge, 707, 708*f*
- Discrete I/O (input/output), 354
- Disc-type mixer, 746, 747*f*
- Disinfection, 6
- Dispersed-growth bulking, 390–391
- Dissolved air flotation (DAF)
 defined, 209, 658, 675
 general methods of, 692
 operation, 700–702
 performance of, 695–699
 reactor, 693
 recycle-flow DAF units, 693, 694*f*
 troubleshooting, 702–704
- Dissolved oxygen (DO), 144, 220, 458,
 472, 811
- Dissolved oxygen meters, 360–361
- Dissolved solids, 15
- Distribution system, trickling filters
 containment structure, 120–121
 filter pump station, 122
 secondary clarifier, 122–125
 solids processing equipment, 125
 underdrain system, 121–122
- Drag out, 33
- Drawings
 architecture and structure, 415
 civil, 415
 electrical, instrumentation, and control,
 416–417
 general, 414–415
 process and mechanical, 415–416
- E**
- Ecosystem management, 262–263
- Effluent, 3, 454, 656
- Effluent effect, 25
- Effluent recycle, 588–589
- Egg-shaped digester (ESD), 737, 738*f*
- Electroplating, 39–40
- Emergency Planning and Community
 Right-To-Know Act of 1986
 (EPCRA), 86–87
- Emulsion cleaning, 39
- Endogenous respiration, 144, 227, 500, 808
- Enhanced biological control process
 Bardenpho process, 534–537
 enhanced SVI control, 541–544
 multiple processing objectives
 operating strategy, 534
 process control, 533
 system flexibility, 533–534
- Dewatering and volume reduction
 centrifugation, 860
 filtration
 belt filter press, 848–854
 filter press, 840–848
 rotary press, 857–860
 screw press, 854–857
 reasons, 839–840
 sludge drying
 heat drying, 870–875
 sand drying beds, 861–867
 surfaced drying beds, 867–870
 sludge incineration
 fluidized bed incinerator, 878
 multiple hearth incinerator, 874, 876*f*,
 877–878
 operation, 880–883
 performance, 878–880
 troubleshooting, 883–884
- Dew point, 763
- Diatomaceous earth, 845
- Diffused aeration, 281, 380–382
- Diffused air systems
 air distribution system, 297–298
 air headers, 298–300
 blowers, 284–292
 diffusers, 292–296
 nitrogen removal, 282–284
- Diffuser
 coarse bubble diffusers, 292–293
 defined, 281
 fine bubble diffusers, 293–294
 inspection, 425
 maintenance, 295–296
 operational procedures, 294
 safety, 296
- Digester, 673
- Digester gas collection
 components and accessories, 754, 754*f*
 gas dome, 754
 meters, 760
 moisture traps, 758–760
 pressure- and vacuum-relief valves, 754, 756
 pressure regulator, 760–761
 thermal protection devices, 756–758
 troubleshooting guidelines, 754, 755*f*
 waste gas burner, 761
- Digester gas treatment
 digester gas storage, 764–765
 digester gas use, 765–766
 hydrogen sulfide removal, 762, 763*f*
 moisture removal, 763–764
 siloxane removal, 764
- Digester heating, 749, 751*f*–753*f*
- Digester mixing
 gas mixing, 745, 746*f*
 mechanical mixing, 745–749, 750*f*
- Digester operation
 decanting, 779, 779*f*–781*f*
 digester feeding, 773–774
 enzymes, 777
 foaming, 777–778

- optimizing nitrogen and phosphorus removal, 538–541
 - reviewing plans and specifications
 - enhanced nitrogen oxidation, 549–550
 - enhanced nitrogen removal, 550–551
 - enhanced phosphorus control, 549
 - enhanced SVI control, 551
 - overall facility, 544–548
 - sequencing batch reactors, 537–538
 - Enhanced biological phosphorus removal
 - abnormal and emergency operating conditions, 508
 - equipment, 503–504
 - luxury uptake of phosphorus, 500, 501*f*, 502*f*
 - maintenance, 508–509
 - operation, 504–506
 - loading guidelines, 506
 - solids management, 507
 - phosphorus removal efficiency
 - calculation, 509
 - Phostrip system, 501
 - reviewing plans and specifications, 509–511
 - safety, 502–503
 - shutdown, 507–508
 - solids and sludge handling facilities, 511
 - startup, 504
 - Entrained biogas, 625
 - Entrain, 281, 547
 - Environmental Protection Agency (EPA), 60–61
 - Enzymes, 777
 - EPA reporting requirements
 - baseline monitoring reports (BMR), 80–81
 - compliance schedule, 81
 - final compliance report, 81
 - hazardous waste disposal reporting, 82–83
 - notification of violations or discharge changes, 82
 - periodic compliance reports, 81–82
 - reporting special problems, 82
 - Equalizing basin, 591–592
 - Etching, 41
 - Eutrophication, 495
 - Exfiltration, 20
 - Expanded granular sludge blanket (EGSB), 564, 564*t*, 568–569
 - Extended aeration, 466
- F**
- Facultative bacteria, 111, 225, 560, 730
 - Facultative lagoons, 838–839
 - Facultative sludge storage lagoons, 838–839
 - Fats, oil, and grease (FOG), 658
 - Fermentation process, 560–561
 - Ferric chloride, 515–516
 - Filamentous bacteria, 266–268
 - Filamentous bulking, 389–390
 - Filamentous foams, 543–544
 - Filamentous organisms, 179, 227, 531
 - Filter classification, trickling
 - high-rate filters, 149–150
 - intermediate-rate filters, 149
 - low-rate trickling filters, 149
 - nitrifying trickling filters, 150–151
 - roughing filters, 150
 - Filter press, 840–848
 - Filtration-based dewatering processes
 - belt filter press, 848–854
 - filter press, 840–848
 - rotary press, 857–860
 - screw press, 854–857
 - Final compliance report, 81
 - Fine bubble diffusers, 293–294
 - Fine/coarse bubble-diffused air systems, 545
 - 5-day BOD (BOD_5), 143–144, 459, 667
 - Fixed film. *See also* Activated sludge process
 - defined, 110, 221
 - first biological treatment, 110
 - rotating biological contactors, 170–189
 - submerged fixed film, 189–210
 - trickling filters, 110–170
 - Fixed film reactors
 - hydraulic loading, 478
 - operating ranges for combined state full nitrification, 477, 478*t*
 - organic loading, 478
 - oxygen and flow variations, 479
 - oxygen transfer, 478
 - packed towers, 474
 - rotating biological contactors, 473, 474, 476–477
 - sloughing off organisms, 479
 - temperature variations, 479
 - trickling filters, 473–475
 - Fixed mounted aerators, 300–303
 - Flagellates, 268–270, 269*f*
 - Flame arresters, 756–757, 757*f*
 - Flights, 323, 695
 - Float, 357
 - Floatable solids, 15
 - Floating surface aerators, 303
 - Flocculation, 222, 497, 521
 - Flocs, 223, 503
 - Flow control equipment, 311–312
 - Flow control gates, valves, and weirs, 423
 - Flowmeters, 360
 - Flow pattern
 - complete mix, 312–313
 - contact stabilization, 316–317
 - flow control equipment, 311–312
 - plug flow, 312
 - step-feed, 313–316
 - Fluidized beds
 - defined, 483, 573
 - and expanded bed reactors, 565
 - incinerator, 878
 - Flux, 327
 - Foam control, 543–544
 - Foaming, 383–387
 - Food/microorganism (F/M) ratio, 183, 227, 245–246, 466
 - Free oxygen, 190, 460, 612
 - Free water, 719
 - Fungi, 111, 223, 271
- G**
- Gas collection and handling, 624–625
 - Gasification, 143
 - Gauges and sensors, 361–362
 - Generation and discharge frequency
 - continuous and intermittent discharges, 57–59
 - hours of operation and discharge, 55–57
 - Grab samples, 140, 241
 - Gravity belt thickeners
 - blinding, 720
 - free water, 719
 - operation, 723–724
 - performance, 721–723
 - porosities, 720
 - troubleshooting, 724–725
 - Gravity thickeners
 - operation, 681–683
 - performance, 675–681
 - troubleshooting
 - liquid surface, 684
 - thickened sludge concentration, 684–692
 - Grit, 656
 - Growth rates, 228, 667
 - and life cycles, microorganisms, 272
- H**
- Hazard Communication Standard (HCS), 87–88
 - Hazardous material regulations, 89–90
 - Hazardous sludge, 659
 - Hazardous waste, 661–664
 - Hazardous waste disposal reporting, 82–83
 - Hazardous waste laws, 97–98
 - Headers, 281
 - Head loss, 192, 292
 - Headworks, 224, 539, 682
 - Heat drying, 870–874
 - Heterotrophic bacteria, 459
 - Heterotrophs, 146, 266
 - High-purity oxygen systems, 282, 341–343, 342*f*
 - High-rate filters, 149–150
 - Hot water-based heat exchangers, 593
 - Human machine interface (HMI), 288
 - Humus sludge, 773

- Hybrid anaerobic process, 607–608
 Hybrid anaerobic reactors, 566, 574–575
 Hydraulic loading, 232, 477, 478
 Hydraulic retention time (HRT), 199, 585–586
 Hydrazine dehydrogenase, 494
 Hydrazine synthase, 494
 Hydrogen sulfide, 163, 561, 609–610, 625
 Hydrolysis, 499, 560, 731
 Hydrophobic, 764
- I**
- Immiscible, 21
 Indirect dischargers, 350
 Indole, 778
 Industrial Categorical Pretreatment Standards
 categories exempt from EPA, 74
 category determination requests, 74
 EPA-regulated categories, 73–74
 EPA regulation development process, 70–73
 local limits for noncategorical industries, 74–75
 Industrial wastestream variables
 compatible and noncompatible pollutants, 51–52
 concentrated solutions, 52–53
 dilute solutions, 52
 generation and discharge frequency, 55–59
 pollutant concentration and mass, 53–55
 Industrial waste treatment system (IWTS)
 collection system
 flammables, 21
 hydraulic capacity problems, 17
 industrial wastestream variables, 51–59
 industrial wastewater facility operators, 98–101
 industrial wastewater sources, 34–51
 natural cycles, 3
 needs of, 5
 odors, 18–19
 pH problems, 19–21
 plugging, 18
 pollution prevention, 27–34
 regulatory requirements, 59–98
 temperature, 21–22
 waste discharges, 11–26
 water uses, 5–10
 Industrial wastewater, 218
 Industrial wastewater effects
 on collection system, 17–22
 on effluent and sludge disposal and reuse, 25
 on POTW, 25–26
 on treatment system, 22–25
 Industrial wastewater facility operators, 98–101
- Industrial wastewater sources
 industrial wastewater treatment system (IWTS), 50–51
 maintenance activities, 49–50
 manufacturing processes, 36–47
 utility processes, 47–49
 Industrial wastewater treatment
 breweries, 439–441
 dairies, 437–439
 petroleum refineries, 445–446
 pulp and paper, 441–445
 Infiltration, 21
 Influent, 464
 Influent effects, 237–238
 Influent wastewater flow, 666
 Inoculation, 745
 Inorganic solids, 15
 Inorganic waste, 11
 Inspection
 air filters, 423–424
 air headers, 424–425
 blowers and compressors, 425–427
 diffusers, 425
 flow control gates, valves, and weirs, 422–423
 RAS/WAS pumping system, 427–428
 secondary clarifiers, 427
 water sprayers, 423
 Integrated fixed film activated sludge (IFAS) process, 192–194
 Interference, 23
 Intermediate-rate filters, 149
 Internal circulation UASB, 572
 Ion exchange, 492–493
 Ionized ammonia, 486
- J**
- Jar testing, 512
 Job shop, 84
- K**
- Kjeldahl nitrogen, 237, 454, 579
 Kraus process, 340–341, 341*f*
- L**
- Land disposal restrictions (LDRs), 664–665, 665*t*
 Land use ordinances, 97
 Launderers, 276
 Lime precipitation for phosphorus removal
 abnormal and emergency conditions, 526–527
 coagulation, 521
 equipment
 clarification process, 522–523
 lime feed, 521–522
 mixing chamber, 522
 pumps and piping, 523
 flocculation, 521
 loading guidelines, 529–530
 maintenance, 527–528
 operation, 523
 recarbonation and calcium carbonate recapture, 524–526
 reviewing plans and specifications, 530
 sampling and analysis, 523–524
 sedimentation, 521
 Lime recalcining recovery process, 507
 Lipophilic, 25
 Liquid–solids separation, 533
 Local collection system disposal codes, 95–96
 Local wastewater ordinances and codes
 additional statements, 90–91
 administrative fine penalties, 91–92
 EPA minimum requirements, 92–93
 industrial wastewater limitations, 93–95
 industrial wastewater prohibitions, 93
 misdemeanor and felony criminal actions, 95
 Lockout/tagout, 260, 646
 Lower explosive limit (LEL), 797
 Low-rate trickling filters, 149
- M**
- Machining, 37
 Macronutrients, 579, 580*t*
 Manometers, 401
 Manual drip trap, 759, 759*f*
 Manufacturing processes
 metal finishing industries, 37–44
 printed circuit board manufacturing, 44–47
 Mean cell residence time (MCRT), 247, 464, 497, 498, 533, 543
 Mechanical aeration, 382–383
 Mechanical aerators, 281–282
 Mechanical draft tube propeller mixers, 746, 747*f*
 Mechanical stirring mixer, 746, 747*f*
 Mechanical surface aerators, 545
 Media, 110, 573
 trickling filters
 plastic media, 116–117
 rock media, 115–116
 Membrane bioreactor (MBR), 344–345, 570
 Membrane gas storage, 764, 764*f*
 Mercaptans, 18, 163, 778
 Mesophilic bacteria, 266
 Mesophilic digestion, 730
 Metabolism, 482
 Metal finishing industries
 anodizing, 40–41
 bright dipping process, 41
 cleaning and surface preparation, 37–39

etching and chemical milling, 41
 machining, 37
 plating and coating, 39–40
 process waste characteristics, 41–43
 wastewater generation, 43
 Metazoa, 270–271
 Methane formers, 562
 Methane-forming bacteria, 562
 Microbial processes, nitrification, 459–461
 Microbiology of activated sludge, 261–262
 ecosystem management, 262–263
 microorganisms in activated sludge,
 264–272
 microscopic assessment and
 observations, 273–279
 Microfiltration (MF), 345
 Microns (μm), 264
 Micronutrients, 580–581
 Microorganisms
 algae, 271
 in anaerobic treatment processes, 562
 bacteria, 264–268
 defined, 218, 219
 fungi, 271
 growth rates and life cycles, 272
 metazoa, 270–271
 protozoa, 268–270
 viruses, 271
 Milligrams per liter (mg/L), 11, 558
 Miscible, 21
 Mixed liquor, 124, 219, 220, 464
 Mixed liquor suspended solids (MLSS), 227
 load ratio, 241–242
 organic matter stabilization, 242
 respiration rate, 240–241
 Mixed liquor volatile suspended solids
 (MLVSS), 227, 473
 Mixed media, 117
 Mixed waste, 663
 Mixers, 306
 submersible mixers, 307
 surface-mounted mixers, 307
 Modified Ludzack-Ettinger and Wuhrmann
 processes, 337–339
 Molecular weight, 731
 Monod kinetics, 467
 Moving and fixed bed biological reactor
 (MBBR) processes, 191–192
 Multiple hearth incinerator, 874, 876f,
 877–878

N

Nanofiltration (NF), 345
 National Pollutant Discharge Elimination
 System (NPDES) permit, 220, 221,
 497
 National Pretreatment Program
 categorical standard modifications, 83–85
 categorical standard types, 75–76
 EPA reporting requirements, 79–83

General Pretreatment Program, 64–67
 Industrial Categorical Pretreatment
 Standards, 68–75
 Prohibited Discharge Standards, 67–68
 total toxic organics (TTO), 77–78
 wastestream types, 76–77
 Nephelometric turbidity units (NTUs), 361
 Nitrification
 defined, 110, 222, 458
 efficiency
 vs. ammonia concentration, 461, 462f
 vs. dissolved oxygen, 461, 462f
 overall efficiency calculation, 463–464
 vs. pH, 461, 462f
 vs. temperature, 463, 463f
 fixed film reactors, 473–479
 laboratory reporting and regulatory
 compliance, 479–480
 microbial processes, 459–461
 suspended growth reactors, 464
 alkalinity and pH, 468–472
 dissolved oxygen, 472
 nitrogen levels, 472
 nitrogenous food, 473
 temperature, 472–473
 time under aeration, 466–468
 troubleshooting, 480–482
 Nitrifying trickling filters, 150–151
 Nitrite-oxidizing bacteria (NOB), 459–461,
 466
 Nitrogen cycle, 4
 Nitrogen forms and processes, 459, 460f
 Nitrogen levels, 472
 Nitrogenous food, 473
 Nitrogen removal
 ammonia stripping, 486–490
 anammox treatment process, 493–495
 breakpoint chlorination, 490–492
 combined and separate stage removal,
 465f
 denitrification, 458, 482–486
 ion exchange, 492–493
 nitrification, 458–482
 overland flow systems, 495
 systems, types of, 458, 459
 uses, 458
Nocardia foam. *See* Filamentous foams
 Noncompatible pollutants, 23
 Non-hazardous sludge, 659
 Nonvolatile (in organic) matter, 658
 Normality, 629
 NPDES permit program, 62–64
 N (normal) solution, 627
 Nutrient, 3, 145, 454
 Nutrient cycle, 3
 Nutrient removal
 biological wastewater treatment
 processes, 454–458
 enhanced biological control, 531–551
 nitrogen removal, 458–495
 phosphorus removal, 495–530
 Nutrient requirements, 579–581

O

Obligate aerobes, 460
 Occupational Safety and Health
 Administration (OSHA), 259
 Odor control, 625–626
 Olfactory fatigue, 625
 Organic loading rate (OLR), 127–129,
 575–577
 Organic matter stabilization, 242
 Organic solids, 15
 Organic waste, 11
 OSHA. *See* Occupational Safety and Health
 Administration (OSHA)
 OSH Act of 1970, 260
 Overland flow systems, 495
 Oxidic solids retention time (oSRT), 466
 in acidic waters, 468, 469
 in alkaline waters, 468, 469
 based on dissolved oxygen
 concentration and water
 temperature, 467–468
 Oxidation, 146, 223, 599
 Oxidation ditch, 343
 Oxidation–reduction potential (ORP), 24,
 340, 361, 539
 Oxidizing agent, 361

P

Packed towers, 474
 Parts per million (ppm), 762
 Passivating, 40
 Pass-through of pollutants, 24
 Pathogenic organisms, 12, 144, 220, 658,
 659
 Performance data sheet, UASB system,
 619f
 Periodic compliance reports, 81–82
 Permeate, 344
 Permissible exposure level (PEL), 625
 Petroleum refineries
 operation, 445
 treating toxic substances, 445–446
 pH, 14, 145, 460, 561
 adjustment, 578–579
 alkalinity and, 468–472
 extremes, 634–635
 meters, 361
 Phosphorus removal
 biological process
 enhanced process, 500–511
 mean cell residence time, 497, 498
 phosphorus accumulating organisms,
 497, 498f
 process configurations, 499–500
 chemical process
 aluminum sulfate, 513–515
 chemical injection locations, 516–518
 ferric chloride, 515–516
 maintenance, 519–520

- Phosphorus removal (*continued*)
 reviewing plans and specifications, 520
 sludge production, 518–519
 lime precipitation, 521–530
- Phostrip system, 501
- Pig, 19
- Pilot study, 771
- Pinpoint floc, 240, 393
- Plastic media, trickling filters, 116–117
- Plug flow, 280, 312, 568
- Plug flow aeration system, 465
- Plug flow anaerobic system, 572–573
- Plug flow reactor, 181
- Point sources, 60
- Pollution prevention
 best management practices (BMPs), 31–33
 economic benefits, 30
 material substitution, 33
 pollution control and prevention regulations, 29–30
 process modification, 33–34
 product reformulation, 34
 switching from treatment to, 28
- Polyelectrolytes, 390, 524
- Polymer, 227, 500, 695
- Porosity, 720
- Positive displacement blowers, 285
- Positive displacement pumps, 307
- Post-treatment units
 biogas handling system, 609–610
 biomass handling system, 608
- Precipitation, 454, 658, 659
- Precoat, 842
- Preliminary sludge processing, 671–673
- Pressure regulator, 760, 760*f*
- Preventive maintenance of anaerobic treatment system, 647–650
- Primary clarifier, 659
- Primary sludge, 666–667
- Primary treatment, wastewater, 11
- Printed circuit board manufacturing, 44–47
- Priority pollutants, 70
- Process monitoring and control
 RBC
 biofilm thickness, 181–182
 disc submergence, 181
 hydraulic loading rate, 180
 organic loading rate, 179–180
 oxygen supply/transfer, 180–181
 recirculation rate, 182
 rotational speed, 181
 water and ambient temperature, 182
 submerged fixed film
 biomass parameters, 202
 equivalent suspended solids concentration, 201–202
 hydraulic retention time (HRT), 199
 media parameters, 199–200
 oxygen parameters, 203
 sieve approach velocity, 202–203
 substrate parameters, 200–201
 trickling filters
 daily process monitoring, 141–146
 dosing rate, 131–135
 hydraulic loading rate, 129–131
 organic loading rate, 127–129
 oxygen supply, 138–140
 recirculation ratio, 135–136
 removal efficiencies, 136–138
 sampling and laboratory analysis, 140–141
- Process Safety Management of Highly Hazardous Chemicals, 88
- Process variables, 233, 520
- Process waste characteristics, 41–43
- Programmable logic controller (PLC), 347, 539
- Prohibited Discharge Standards, 67–68
- Protozoans, 111, 223, 268–270
- Psychrophilic bacteria, 266, 732
- Publicly owned treatment works (POTW), 9, 25–26, 350, 665
- Pug mill, 830
- Pulp and paper industry
 color and turbidity, 444
 fiber, 443–444
 flow, 444
 foam control, 442–443
 nutrient control, 442
 odor, 445
 pH control, 443
 settleability, 444
 wastewater characteristics, 442
- Putrefaction, 12
- Putrescible, 658
- Q**
- Quicklime, 510
- R**
- Random media, 116
- Rate limiting nutrient, 455–458
- Reaeration tank, 483
- Reagents, 40
- Recarbonation, 508
- Receiving waters, 2, 218
- Recirculation pumps, 307
 maintenance, 308–310
 operation, 308
 safety in pump rooms, 310
- Rectangular clarifiers, 323–324
- Recycle flow effects, 238
- Redfield ratio, 454
- Reducing agent, 361
- Reduction, 337, 591
- Regulated dischargers, 61
- Regulatory requirements
 building codes, 96
 delegation of federal authority, 61
 Environmental Protection Agency (EPA), 60–61
 hazardous waste laws, 97–98
 land use ordinances, 97
 local collection system disposal codes, 95–96
 local wastewater ordinances and codes, 90–95
 National Pretreatment Program, 64–85
 NPDES permit program, 62–64
 other federal statutes and regulations, 85–90
 regulated dischargers, 61
 underground tank laws, 96–97
- Reporting special problems, 82
- Residual solids management
 dewatering and volume reduction
 centrifugation, 860
 filtration, 840–860
 reasons, 839–840
 sludge drying, 860–874
 sludge incineration, 874–884
 preliminary sludge processing, 671–673
 sludge stabilization
 aerobic digestion, 807–827
 anaerobic digestion (*see* Anaerobic digestion)
 chemical stabilization, 827–829
 composting, 829–838
 facultative sludge storage lagoons, 838–839
 sludge thickening
 centrifuge thickeners, 704–719
 dissolved air flotation thickeners, 692–704
 gravity belt thickeners, 719–725
 gravity thickeners, 675–692
 reduced sludge volumes, 674
 rotary drum thickeners, 725–729
 sedimentation, 673
 waste activated sludge (WAS), 673
 solids disposal, 884–885
 solids handling and disposal
 preparing solids for disposal and reuse, 660
 sludge handling methods, 670–671
 sludge quantities, 665–670
 sludge treatment, reuse, and disposal regulations, 660–665
 types and characteristics, 657–660
- Resource Conservation and Recovery Act (RCRA) of 1976, 85–86, 661–662
- Restart procedures, anaerobic treatment, 646–647
- Return activated sludge (RAS), 230, 427–428, 465
- Reverse osmosis (RO), 345
- Reverse thrusting jets, 118
- Reviewing plans and specifications
 chemical phosphorus removal process, 520

- enhanced biological control process, 544–551
 - enhanced biological phosphorus removal, 509–511
 - lime precipitation for phosphorus removal, 530
 - Rising sludge, 315
 - Rock media, trickling filters, 115–116
 - Rotary drum thickeners (RDTs)
 - baffled interior of, 725, 726*f*
 - enclosed, 726, 727*f*
 - operation, 728
 - performance, 727, 728*t*
 - troubleshooting, 728, 729*f*
 - Rotary press, 857–860
 - Rotary screw blower, 286
 - Rotating biological contactors (RBCs)
 - auxiliary instrumentation, 178
 - baffles, 177
 - cover, 177
 - defined, 110, 461, 474
 - drive mechanisms, 175–176
 - equipment inspection and preventive maintenance, 188
 - influent/effluent piping, 177–178
 - media, 172–175
 - modes of operation, 182–185
 - process monitoring and control, 179–182
 - reviewing plans and specifications, 186
 - shutdown procedures, 187–188
 - startup procedures, 186–187
 - tank, 177
 - Rotifers, 264
 - Roughing filters, 150
 - Round clarifiers, 321–323
- S**
- Safety, 259–261
 - Safety data sheet (SDS), 260, 649
 - Sand drying beds, 861–867
 - SBR. *See* Sequencing batch reactors (SBRs)
 - Scale, 504
 - Screw press, 854–857
 - Scum, 324, 656
 - Secchi disc, 362, 362*f*
 - Secondary clarification, 230–232, 317
 - configurations, 321–324
 - design guidelines, 318–321
 - operation and maintenance, 324–326
 - state point analysis, 326–335
 - Secondary clarifier, 218, 220, 427, 465, 658, 659
 - Secondary sludge, 667–669
 - Secondary treatment, 12, 218
 - Sedimentation, 521, 673
 - Sedimentation basin, 471, 666
 - Seed sludge, 735
 - Segregation, 32
 - Seizing, 291
 - Selector, 227, 480
 - Selector recycle, 532
 - Separate sludge post-denitrification, 485
 - Septic, 3, 126, 240, 658, 659
 - Septicity, 275, 673
 - Septic sludge, 395–396
 - Septic wastewater, 537
 - Sequencing batch reactors (SBRs), 344–347, 346*f*, 347*f*, 348*t*, 537–538, 572
 - Set points, 234
 - Settleability, 256–258
 - Settleometer, 15
 - Shock loads, 313, 565, 771
 - Short-circuiting, 118, 233, 523, 574
 - Shutdown procedures, anaerobic reactor, 645–646
 - Sidestream, 344, 603
 - Sieve approach velocity, 202–203
 - Significant industrial user (SIU), 66
 - Single sludge post-denitrification, 485
 - Single sludge pre-denitrification, 485
 - Skatole, 778
 - Slake, 502
 - Sloughings, 111, 603
 - Sludge, 219, 220, 656
 - Sludge age, 228, 246–252, 466
 - Sludge blanket depth, 253–256
 - Sludge disposal and reuse, effect of, 25
 - Sludge drying
 - heat drying, 870–875
 - sand drying beds, 861–867
 - surfaced drying beds, 867–870
 - Sludge handling methods, 670–671
 - Sludge incineration
 - fluidized bed incinerator, 878
 - multiple hearth incinerator, 874, 876*f*, 877–878
 - operation
 - alarm systems, 881–882
 - burnout, 882–883
 - safety, 883
 - temperature and pressure ranges, 881, 881*t*
 - performance
 - air supply, 879
 - burner location and firing rate, 879
 - shaft speed, 879–880
 - sludge feed rate and quality, 878–879
 - troubleshooting, 883–884
 - Sludge processing methods, 670, 671*t*
 - Sludge quantities
 - primary sludge, 666–667
 - secondary sludge, 667–669
 - sludge volumes, 669–671
 - Sludge stabilization
 - aerobic digestion
 - operation, 817–821
 - performance, 811–816
 - process description, 808–811
 - troubleshooting, 823–827
 - typical performance, 821–823
 - anaerobic digestion
 - controls and test interpretation, 782–794
 - digester cleaning, 794–796
 - digester gas collection, 753–761
 - digester gas treatment, 761–766
 - digester heating, 749, 751*f*–753*f*
 - digester mixing, 745–749
 - digester operation, 772–781
 - example of actual operation, 805–807
 - operational strategy, 797–804
 - performance, 766–772
 - process description, 730–734
 - safety, 797
 - system components, 735–744
 - troubleshooting, 804, 805*t*
 - chemical stabilization, 827–829
 - composting
 - guidelines, 829–830
 - operation, 836–837
 - performance, 833–836
 - static pile, 830
 - troubleshooting, 837, 838*f*
 - windrow method, 830, 832*f*
 - facultative sludge storage lagoons, 838–839
 - Sludge thickening
 - centrifuge thickeners, 704–719
 - dissolved air flotation thickeners, 692–704
 - gravity belt thickeners, 719–725
 - gravity thickeners, 675–692
 - reduced sludge volumes, 674
 - rotary drum thickeners, 725–729
 - sedimentation, 673
 - waste activated sludge (WAS), 673
 - Sludge treatment, reuse, and disposal regulations
 - hazardous waste, 662–664
 - land disposal restrictions, 664–665
 - solids discharged to POTWs, 665
 - solid waste, 661–662
 - Sludge volume index (SVI), 232, 242–245, 539, 541–544
 - Sludge/volume (S/V) ratio, 680
 - Sludge volumes, 669–671
 - Slug, 82, 382
 - Slurry, 501
 - Solenoid, 290
 - Solid bowl centrifuge, 705–706
 - Solids, 658
 - Solids discharged to POTWs, 665
 - Solids disposal, 884–885
 - Solids handling and disposal
 - preparing solids for disposal and reuse, 660
 - sludge handling methods, 670–671
 - sludge quantities, 665–670
 - sludge treatment, reuse, and disposal regulations, 660–665
 - types and characteristics, 657–660
 - Solids handling methods, 656, 657*f*

- Solids in wastewater
 - dissolved solids, 15
 - floatable solids, 15
 - organic and inorganic solids, 15
 - suspended solids, 15
 - total solids, 14–15
 - Solids retention times (SRTs), 193, 228, 247–250, 464, 466, 498, 568, 585
 - Solids wasting, 587–588
 - Solid waste, 661
 - Solvent management plan, 77
 - Specific gravity, 658
 - Speed-retarder orifices, 118
 - Spiral heat exchangers, 593, 749, 751*f*
 - Spülkraft (SK) rate, 131
 - Stabilization, 12, 223, 562, 656, 657*f*
 - Standard cubic feet per minute (SCFM), 284, 698
 - Startup procedure, anaerobic reactor, 614–617
 - State point analysis, 326–335
 - Step-feed aeration, 270, 466
 - Stiff white foam, 384–385, 384*f*
 - Stormwater regulations, 88–89
 - Straggler flocs, 393
 - Stratification, 365, 707
 - Struvite, 591, 648, 779
 - Submerged fixed film
 - aeration system, 197–198
 - fixed media, 195
 - free-floating media, 195–196
 - integrated fixed film activated sludge process, 192–194
 - media retention sieve, 197
 - mixers, 198
 - modes of operation, 204–207
 - moving and fixed bed biological reactor processes, 191–192
 - process monitoring and control, 198–203
 - reviewing plans and specifications, 208–209
 - startup and shutdown procedures, 209
 - troubleshooting, 210
 - Submerged turbine aerators, 545
 - Submersible mixers, 307
 - Substrate, 193, 227, 471, 577
 - Supernatant, 224, 501, 682
 - Supervisory control and data acquisition (SCADA) system, 287, 520, 782
 - Surface-active agents, 33, 364
 - Surface aerators
 - fixed mounted aerators, 300–303
 - floating surface aerators, 303
 - maintenance, 304–305
 - operation, 304
 - safety, 305
 - turbine aerator, 303–304
 - Surfaced drying beds, 867–870
 - Surface loading rate, 129
 - Surface-mounted mixers, 307
 - Suspended growth anaerobic reactors
 - anaerobic contact process, 570
 - anaerobic lagoons, 571–572
 - anaerobic membrane bioreactor, 570–571
 - anaerobic sequencing batch reactor, 572
 - continuously stirred tank anaerobic reactor, 569–570
 - expanded granular sludge blanket reactor, 568–569
 - internal circulation UASB, 572
 - plug flow anaerobic system, 572–573
 - upflow anaerobic sludge blanket reactor, 568, 569*f*
 - Suspended growth processes, 111, 221, 460
 - Suspended growth reactors
 - in denitrification process, 484–486
 - in nitrification process, 464
 - alkalinity and pH, 468–472
 - dissolved oxygen, 472
 - nitrogen levels, 472
 - nitrogenous food, 473
 - temperature, 472–473
 - time under aeration, 466–468
 - Suspended solids, 15, 122, 220, 464, 563, 666
 - System startup and shutdown, activated sludge processes, 412–413
 - inspection, 421–428
 - instrumentation and control, 431–432
 - long-term shutdown and restarting, 434–436
 - reviewing plans and specifications, 413–421
 - short-term shutdown, 433–434
 - startup procedures, 428–431
- T**
- Target secondary effluent quality, 350–351
 - Thermal valve, 758, 758*f*
 - Thermophilic bacteria, 266, 730
 - Thickening, 656, 657*f*
 - Time-weighted average (TWA), 291
 - Titrate, 627
 - Total Kjeldahl nitrogen method, 579, 633
 - Total nitrogen components, 454*f*
 - Total organic carbon (TOC), 484, 575
 - Total solids, 14–15
 - Total suspended solids (TSS), 143, 361, 498, 563
 - Toxic and inhibitory substances, 581–583
 - Toxic gases, 742
 - Toxicity, 380, 383
 - Toxic organics, 25
 - Toxic substance, 14
 - Transpiration, 3
 - Treatment system effects
 - hydraulic overload, 22–23
 - influent variability, 23–24
 - interference, 23
 - slug loadings, 24–25
 - Trickling filter humus, 773
 - Trickling filters
 - construction, startup, and shutdown, 154–158
 - defined, 110, 474
 - distribution system, 117–125
 - filter classification, 146–151
 - media, 111–117
 - modes of operation, 151–152
 - operation and maintenance, 158–162
 - process monitoring and control, 126–146
 - reviewing plans and specifications, 153–154
 - safety, 125–126
 - troubleshooting, 162–170
 - Troubleshooting
 - aerobic digestion
 - foaming, 827
 - guide, 823, 824*f*–825*f*
 - loadings, 827
 - residual DO upset, 825
 - temperature and pH, 825–826
 - ammonia stripping process, 489–490
 - centrifuge thickeners
 - basket centrifuge, 718–719
 - disc-nozzle centrifuge, 719
 - solid bowl centrifuge, 716–718
 - digested sludge, 638
 - dissolved air flotation (DAF), 702–704
 - fixed reactor covers, 642
 - gravity belt thickeners, 724–725
 - gravity thickeners
 - liquid surface, 684
 - thickened sludge concentration, 684–692
 - nitrification process, 480–482
 - reactor effluent, 643
 - reactor gas system, 641–642
 - reactor loading, 637
 - reactor temperature control (external heat exchangers), 639
 - solids mixing (mechanical mixers), 640
 - solids pumping and pipelines, 638
 - toxicity, 644
 - trickling filters
 - trickling filter process, 163–168
 - upstream and downstream treatment processes, 169–170
 - Tube-in-tube heat exchanger, 594, 749, 751*f*
 - Turbidity, 270
 - Turbidity meters, 360, 361
 - Turbidity units, 361
 - Turbine aerator, 303–304
 - Turbo blowers, 287
- U**
- Ultrafiltration (UF), 345
 - Underdrain system, 121–122
 - Underground tank laws, 96–97

Unionized ammonia, 486
 University of Cape Town (UCT) process, 339
 Upflow anaerobic sludge blanket (UASB) reactor
 advantages, 597–598
 granular sludge, 595–596
 organic loading, 600–601
 process components, 598–600
 schematic representation, 594, 595*f*
 upflow velocity, 601
 Upflow anaerobic sludge blanket (UASB) system, 564, 564*t*, 565
 Upset digester, 772
 Utility processes, 47–49

V

Variable frequency drive (VFD), 286
 Vector, sludge solids, 660
 Vertical-flow media, 116–117
 Very dark or black foam, 387, 388*f*
 Viruses, 271

Viscosity, 511
 V-notch weir, 230
 Volatile, 21, 227
 Volatile acid alkalinity, 627
 Volatile acids, 499, 626–630, 770
 Volatile fatty acids (VFAs), 339, 561, 583–584, 616, 621
 Volatile solids, 237, 259

W

Waste activated sludge (WAS), 224, 258–259, 673
 pumps, 427–428
 volatile solids inventory, 259
 Waste discharges
 human health, 12–13
 industrial wastewaters effects, 16–26
 other effects, 14
 oxygen depletion, 11–12
 sludge and scum, 11
 solids in wastewater, 14–15
 Waste gas burner, 761, 761*f*

Wastewater, 2
 Wastewater facilities, 91
 Wastewater generation, 43
 Wasting system, 232–233
 Water bath heat exchanger, 594
 Water hammer, 735
 Water quality changes, 376–377
 Water reuse, 26
 Water sprayers, 423
 Water uses
 agricultural use, 8
 drinking water, 5–7
 fish, wildlife, and aquatic vegetation, 8
 industrial use, 8–10
 recreation, 7–8
 Weir, 253, 422–423
 Wet oxidation, 833
 Wetting rate, 129
 Windrow method, 830, 832*f*

Z

Zeolite, 492